Some Recent Developments in Network Economics

Anna Nagurney
Isenberg School of Management
University of Massachusetts
Amherst, MA 01003
Appears in *Networks* **41** (2003), pp. 68-72.

Abstract This report highlights some recent developments in Network Economics based on papers presented at the Computing in Economics and Finance (CEF 2002) Conference held in Aix en Provence, France.

Key words: network economics, network industries, network effects, financial networks, electronic trade networks, electronic commerce, network commerce and security, telecommunication networks, supply chain networks, transportation networks, supernetworks

Conference Report

The Eight International Conference of the Society for Computational Economics - Computing in Economics and Finance (CEF 2002) - was held in Aix en Provence, France, June 27-29, 2002. The conference is an annual conference and its venue alternates between sites in Europe and in North America. The conference has previously been held in: Barcelona, Cambridge, and Geneva, and in Austin, Boston, New Haven, and Palo Alto.

The CEF 2002 conference consisted of parallel sessions and plenary talks on a variety of computational economics and finance themes. The program chairs were: C. Deissenberg, M. Juillard, and P. Malgrange. This year there were also specially organized sessions on Network Economics as well as other sessions in which papers on network topics appeared.

This report first highlights the themes surrounding networks that have garnered the attention of economists and finance researchers. It then discusses the relevant papers in greater detail and concludes with an amplification of the roles of networks that were represented in papers delivered at the conference. Further information about the conference can be found on the site: http://www.cepremap.cnrs.fr/sce2002.html which also contains links to papers that can be downloaded. Links to conference papers accessible from other sites are also given

below, as available.

The study of networks and their applications has had a long tradition in engineering, operations research/management science, as well as in computer science. More recently, the fields of economics and finance have come to be rich sources of network-based applications. Interest from such disciplines has also been supported, in part, by the greater availability and development of network-based methodologies which allow for the computation of solutions to models.

The role of networks in economics and finance has gained prominence for a variety of reasons: 1. the emergence of industries that are clearly network-based, from transportation and logistics companies, to telecommunication, energy, and power companies, which provide the foundations for economies; 2. the recognition of the interdependence between/among many network systems, such as telecommunications with finance; telecommunications with transportation in the form of electronic commerce, for example, and telecommunications with a variety of energy transmission mechanisms; 3. the recognition that new relationships between economic agents in terms of competition and cooperation are giving rise to new supply chains as well as new financial networks; 4. the realization of the importance of networks in terms of infrastructure and the pricing of their usage as well as the management of risk and uncertainty surrounding networks; and 5. interest in the dynamics surrounding networks and their evolution over space and time.

The two sessions on Network Economics were organized by A. Nagurney and the papers were solicited by postings on several electronic mailing lists. First, the papers presented in the Network Economics sessions are summarized below and then other relevant ones from the conference.

The paper, "Using Financial Options to Hedge Transportation Capacity in a Deregulated Rail Industry" by S. M. Law, A. E. MacKay, and J. F. Nolan analyzed the potential of using financial derivatives in the rail industry, which is one of several industries that can be referred to as "network" industries. The study of such financial instruments in this new setting is relevant since, as discussed by the authors, the market for transportation capacity in the North American rail industry, as well as other industries traditionally classified as "natural monopolies," appears "poised for change."

This paper presented a description of what a market in deregulated rail capacity may look like and how it might function. Of particular interest is the potential for financial instruments, such as derivatives on freight capacity, to play a role in both financial and logistics decisions for the players in this industry.

The authors also examined how hedgers can find this market both useful and profitable. Furthermore, since markets for rail capacity and markets for infrastructure capacity in other competitive network-based industries share important similarities, it is expected that the framework developed in the context of the rail industry will be readily applicable to other industries, including markets for electricity transmission and perhaps cable and telecommunications. The paper is paper 2001-06 at:
http://www.rotman.utoronto.ca/bicpapers/2001.htm

The paper, "Modeling Transportion as a Network Industry" by Y. V. Yevdokimov considered production and consumption of transportation services in light of the "network effects" as discussed and developed in the literature on the economics of networks. Such an approach, argued by the author, is an alternative to existing spatial transportation modeling. The latter treats transportation networks in a cartographical sense in which coordinates and geographical locations matter. In contrast, the framework proposed by the author, referred to as a "systems approach," regards transportation networks as a system of compatible devices to move people and freight in terms of system capacity and capacity utilization. Transportation networks are visualized by the author as economic systems with hierarchical structure with vertical and horizontal linkages. According to these principles, transportation networks are defined and incorporated in an economic system that consists of three levels: micro, meso and macro. All three levels are then connected in order to optimize the whole system and to find optimal characteristics of transportation as a component of the system.

The systems approach, according to the author, allows for the incorporation of macroeconomic feedbacks and, as discussed by the author, the inclusion of not only negative externalities (such as congestion which has been much studied in the transportation and economics literature) but, in addition, positive network externalities in the form of consumption. A computer simulation exercise was also presented. This paper can be downloaded through the conference site.

K. Matsuura presented the paper, "Digital Security Tokens in Network Commerce: Modeling and Derivative Application." This paper is a contribution to the emerging area of security economics. The author discussed how financial tools can assist in the security of information in the digital world of network commerce. The paper described a modeling framework for uncertain digital objects distributed in a network society. In particular, Matsuura proposed an abstraction of such objects and defined "security tokens" abbreviated as "setoks" with each setok having associated with it a certain price, value, timestamp, as well as its main contents. Both the price and the value can be uncertain and can cause risks. A number of properties of the setok were defined including the value response to compromise and the price response to compromise as well as refundability and tradability.

Of particular interest in the paper were multiple risks due to digital objects and how financial tools are risk transfer tools. The proposed model is based on applied cryptography and with the use of stochastic theory, several option pricing formulae were derived. The derivatives are based on the value and not on the price.

In addition to the development of a novel theoretical framework, Matsuura also provided a comprehensive discussion of the relationships between information security technologies and economics. This paper can be downloaded through the conference site.

The paper, "The Role of Information in an Electronic Trade Network" by F. Alkemande, H. M. Amman, and J. A. La Poutre examined how evolving networks of trading possibilities change if the information changes. The authors utilized a network economics approach to study electronic trade networks against the backdrop of the growth in electronic commerce which affects the market dynamics significantly. Network economics holds the view that individual actions, and, in turn, the aggregate outcomes, are, in a large part, determined by the interaction structure. This is in contrast with the market view of the economy where buyers and sellers are anonymous and the structure of the interaction is typically considered less important. Alkemande and his co-authors argued that, since as the number of participants is substantially larger, the interaction patterns change, as does the role and the importance of information.

A trade network was modeled by the authors as a co-evolving system of heterogeneous, boundedly rational agents. The network consists of a large number of consumers, producers,

and intermediaries that buy and sell goods over the network. Transactions can only take place if there is a link between the buyer and the seller. The agents have to strategically decide which (costly) links to form or to sever. Agents differ in their preferences, budgets, and information processing capabilities. To model the search and learning process of the agents, the authors used an evolutionary algorithm.

The authors investigated the outcomes that the different types of agents obtain and the trade patterns that arise as well as the influence of (different types of) information on the trade patterns. They also presented simulations of the dynamics of the evolving networks in graphical format.

A. Nagurney presented, "A Supernetwork Framework for Financial Networks with Intermediation with Electronic Transactions," joint with K. Ke. Advances in telecommunication networks, and, in particular, the Internet have transformed the economic landscape for financial decision-making. In this paper, Nagurney and Ke focused on financial networks with electronic transactions and with different tiers of decision-makers and developed an integrated framework for the modeling, analysis, and computation of solutions to such problems. Specifically, they considered an economy consisting of three types of decision-makers: those with sources of funds; intermediary ones, and consumers associated with the financial products at the demand markets. Those with sources of funds can transact with the intermediaries either physically or electronically as well as directly in an electronic manner with the consumers. The intermediaries, in turn, can also transact with the consumers either in a physical or an electronic fashion.

They addressed the behavior of the decision-makers, identified the network structure of the problem, derived the equilibrium conditions, and then established the variational inequality formulation. In addition, the authors proposed a continuous time adjustment process for the study of the disequilibrium dynamics and proved that the set of stationary points of the resulting projected dynamical system coincides with the set of solutions of the variational inequality. Variational inequality theory was utilized to derive qualitative properties of the equilibrium price and financial flow pattern. Finally, the authors applied an algorithm for the determination of equilibrium prices and financial flows in several examples. The paper (under a slightly modified title) can be downloaded from the site: http://supernet.som.umass.edu

under "Download Articles."

O. Berman presented the paper, "Locating Service Facilities to Reduce Lost Demand," co-authored with D. Krass and J. Wang. In the paper, the authors analyzed the problem of locating a set of service facilities on a network when the demand for service is stochastic and congestion may arise at the facilities. They considered two potential sources of demand: demand lost due to insufficient coverage, and demand lost due to congestion. Demand loss due to insufficient coverage arises when a facility is located too far away from customer's location. The amount of demand lost is modeled as a decreasing function of travel distance. The second source of lost demand arises when the queue at a facility gets too long. It is modeled as the proportion of bulking customers in a Markovian queue with fixed buffer length.

After formulating the model, they derived and investigated several different Integer Programming formulations, focusing in particular on alternative representations of closest assignment constraints. The authors also studied a wide variety of heuristic approaches, ranging from simple greedy-type heuristics, to heuristics based on time-limited Branch and Bound, Tabu Search, and random adapted search heuristics. Results of an extensive set of computational experiments were presented and discussed.

J. R. Kearl presented the paper, "Switching, Adding, or Shifting: Network Effects, Network Compatibility, and Lock-In," with G. D. Adams. The speaker noted that "network effects" or "network externalities" have attracted a great deal of attention among academic economists, policy makers, business strategists, and litigants in antitrust matters. The degree to which network effects impose "switching costs" (or "lock in") on consumers is a matter of keen interest to policy makers ("Does the market choose the right technology?"), business strategists ("What is the demand elasticity - and thus the profit maximizing price - of our product?"), and litigants in antitrust matters ("Does the supplier of the good have a monopoly?"). However, despite this attention, there exists widespread ambiguity as to what is meant by "network effects" and the import of such effects on market outcomes. The confusion over the nature of the purported network effects in turn leads to confusion over the likely existence and magnitude of switching costs.

In this presentation, the authors showed that phenomena that commonly fall under the

rubric of network effects may be either: (i) direct (or "own good") network effects; or (ii) indirect (or "complementary good" - network effects). The former involves a cross-good positive externality in that, to give a specific example, an operating system is more valuable and will be more widely adopted if it has many applications that run on it and, conversely, an application written for a particular operating system is more valuable when an operating system is more widely adopted. The "applications barrier to entry" for operating systems advanced in the government's case against Microsoft is an example of this effect. The latter occurs when the value to a consumer increases as more consumers purchase the same product. The paradigmatic example is a telephone where the value to a particular user increases when there are more people who can be reached via phone.

With either type of network effect, "switching costs" are often postulated. To the degree network effects do exist, then these effects will increase the cost of a user exiting one network and "switching" to another network. However, in many instances - including instances where switching costs are thought to be significant - users do not need to leave one network to join another. That is, the two networks are not incompatible (as, for example, in the case of credit card networks). In these cases, it is more appropriate to think of "adding costs." The authors showed that often these adding costs are small - even though switching costs may be large. Finally, the authors showed that members of networks often already belong to more than one network of the same "type." In this case, even "adding costs" overstate the degree to which the user is locked in to a particular network (and that network's complementary goods). In these cases, it is more appropriate to think about "shifting costs."

The authors considered conditions under which switching costs are likely to be large and showed that in many instances, goods that are commonly described as having strong network effects and high switching costs, in fact, exhibit little in the way of customer lock-in. The degree of compatibility between competing networks was shown to be critical.

The paper, "Supply Chain Networks and Electronic Commerce," by A. Nagurney, J. Loo, J. Dong, and D. Zhang, developed a framework for the formulation, analysis, and computation of solutions to supply chain network problems in the presence of electronic commerce. Specifically, the authors considered manufacturers who are involved in the production of a homogeneous product and can now sell and have delivered the product not only to retailers

but also directly to consumers. In addition, the manufacturers can transact with the retailers electronically. Nagurney et al. assumed that both the manufacturers and the retailers seek to maximize their profits, whereas the consumers take both the prices charged by the retailers and the manufacturers, along with the associated transaction costs, into account in making their consumption decisions.

The authors identifed the network structure of the problem, derived the equilibrium conditions, and established the finite-dimensional variational inequality formulation. They, subsequently, utilized variational inequality theory to obtain qualitative properties of the equilibrium pattern. In addition, they proposed a continuous time adjustment process for the study of the disequilibrium dynamics and establish that the set of stationary points of the resulting projected dynamical system coincides with the set of solutions of the variational inequality problem. Finally, they applied an algorithm for the determination of equilibrium prices and product shipments in several supply chain examples. This paper synthesizes Business-to-Consumer (B2C) and Business-to-Business (B2B) decision-making in a supply chain context within the same framework. The paper can be downloaded (under a slightly modified title) at http://supernet.som.umass.edu under "Download Articles."

In addition to the papers and presentations in the Network Economics Sessions at the CEF conference there were also other papers presented on network themes and these are summarized below.

The paper, "A Spatial Price Oligopoly Model for Refined Petroleum Products: An Application to a Brazilian Case," by F. M. Pompermayer, M. Florian, and J. E. Leal focused on the production of refined petroleum products in Brazil and developed a multi-product spatial oligopoly model where the supply functions are not explicitly defined but rather the firms engage in optimizing behavior. The optimization problem facing a firm is that of profit maximization where both the optimization of the operations of the refineries as well as the crude oil production were treated. Conventional oligopoly models that do not consider interactions among the products on the supply side cannot be applied to analyze oligopolies in the petroleum industry. The authors proposed a computational method which was interpreted as a dynamic adjustment process and applied it to illustrative numerical examples. The algorithm computes the equilibrium prices and trading flows of the refined products.

Policy interventions on prices were also discussed and analyzed. This paper can be accessed through the conference site.

The paper, "A Dynamic Market Oriented Model for Network Resource Allocation" by M. Ishinishi and H. Kita proposed a market-oriented model for the allocation of network resources in which software agents trade network bandwidth. The agents are assumed to be utility maximizers, to operate in a decentralized manner, to observe market prices, and to either buy or sell their network resources. The application context is that of digital communications.

Ishinishi and Kita's model has two distinguishing features: 1. a 'futures' market is introduced in order to provide sufficient information regarding prices for the dynamic decision-making and 2. a double auction type is used in contrast to existing models of this ilk that assume a Walrasion tatonnement (adjustment) process in which the auctioneer adjusts the price to balance of supply and demand. In other words, the auctioneer raises the price of the commodity which exhibits excess demand and lowers the price of the commodity that exhibits excess supply. This adjustment process is repeated until the supply of each commodity is equal to its demand.

In the proposed model, in contrast, orders are placed and are collected, as well as the amount and a limit price. The orders are collected for a certain period and in the auction, the price that achieves maximum order matching is searched and contracts are made. Hence, it is expected that the frequency of negotiation in the market can be reduced and that the equilibrium prices can be obtained more quickly that with the classical approach.

The paper,"Phase Transition in Supermarket Chain Network: Multi-Agent System in Soap Froth" by K. Y. Szeto and Chiwah Koh considered the competition between two supermarket chains, in a given two-dimensional cellular network that represents the distribution of shopping malls in a city, in the framework of Multi-Agent Systems. The two-dimensional pattern is based on soap froth: a physical system that possesses a scaling property in the steady state. An economic interpretation was made on the association of cells to a particular choice of color as representative of an agent for a particular chain. The evolution of a color pattern on the static cellular network of soap froth is then interpreted as a manifestation of the competition and cooperation between the two chains. Monte Carlo simulation of the

color pattern using the Ising model for the interaction between the supermarket chains shows the existence of a phase transition from a random phase to a cluster phase at a particular noise level. The existence of different phases is seen also from the analysis of the interior bubble distribution function. This paper is accessible through the conference site.

In addition, there were several papers that focused on the use of neural networks: the paper by M. Yildizoglu, "Connecting Adaptive Behavior and Expectations in Models of Innovation: The Potential Risk of Artificial Neural Networks" which can be downloaded from the conference site and the paper by F. Hoogergeide, J. F. Kaashoek, and H. K. van Dijk, "Efficient Sampling for Non-Standard Distributions Using Neural Network Approximations."

It is clear that many of the issues surrounding networks in economics and finance were represented in the papers at the CEF2002 Conference and were tackled through modeling, analysis, as well as computational approaches. Several papers focused on transportation as a network industry (see the paper by Law, MacKay, and Nolan and by Yevdokimov) and/or had transportation networks as a critical foundation (see, Nagurney et al.). The paper by Law and co-authors emphasized financial tools to address risk on freight networks whereas the paper by Nagurney et al. focused on the interplay between transportation and electronic commerce in the context of supply chains in a network context. The latter paper also recognized competition and cooperation among the various network agents. The paper by Szeto and Chiwah Koh also addressed competition and cooperation in the context of two supermarket chains and applied ideas from physics to model the problem.

The use of tools to address risk was also studied by Matsuura in his paper, which is one of the first to focus on the new area of security economics with a specific emphasis on digital communication networks. Telecommunication networks and their study from a decentralized network resource allocation perspective was the theme of the paper by Ishinishi and Kita. The interplay between different network systems was also the theme carried in the paper by Nagurney and Ke with their emphasis on the modeling and analysis of financial networks with intermediation and with electronic transactions.

Trade networks clearly played a prominent role in several of the papers in the conference, notably, in the paper by Alkemande, Amman, and La Poutre, who not only presented models and algorithms in their presentation but actually displayed the results of their analysis

dynamically through graphical computer simulations. Their work illustrated the evolution of trade networks with producers and with consumers. Trade networks were also modeled but in the more classical setting of oligopolies, by Pompermayer, Florian, and Leal, who recognized the network structure of spatial oligopoly problems and then extended the existing framework to a model motivated by an application to the petroleum industry.

Finally, there was clear recognition of network externalities, both positive ones as well as negative ones and the conceptualization of such effects in the context of networks and industries that have grown around them.

In conclusion, the topic of networks is gaining deep and wide attention from researchers in the fields of economics and finance. The papers presented at the conference suggest new areas of research as well as new directions for more established topics. We can expect more interdisciplinary research on networks as networks in myriad forms attract continued attention due to the deep questions surrounding them and their use in our economies and societies today.